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Valorization of Empty Palm Oil Fruit Bunch Fiber as Hydrophobic Cement Board

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Abstract

The penetration of property business and technology has increased significantly increased due to economic improvement. One of the materials in high demand is cement board. Cement board compost of agricultural waste limits its application due to its easily absorbing water. Herein, we used the empty palm oil fruit bunch as a filler in cement board and coated it with polystyrene from styrofoam waste. The board shows good mechanical strength and fulfill the minimum requirement for cement board standard of Indonesian National Standard (SNI). The board also shows hydrophobic properties, and no water droplets permeate the surface even after 4 h. These findings open a new application for cement board not only for the interior but also for the exterior.

INTRODUCTION

Wood is frequently used as interior or exterior material for buildings. Indonesian wood production is still limited (25 million m^3), while demand achieves 75 million m^3 per year (Wardani et al., 2018). Concrete or cement board made of natural fiber as reinforced fiber or matrix and cement as a filler is a potential material for the interior due to its design and manufacturing flexibility, termite resistance, and fire risk. Natural fiber from agricultural waste will increase its economic value and more sustainable (Hamid et al., 2023; Matyskova et al., 2024). Empty palm oil fruit bunch is one of the main agricultural wastes in Indonesia and its increases in production increase every year. 90% of its oil production is associated with waste biomass from palm leaves, empty fruit bunch, or palm kernel shells (Caroko et al., 2020; Hidayatulloh et al., 2021). A fresh fruit bunch generates 13.5% mesocarp fibers, 22% of empty fruit bunch (EFB), and 5.5% of palm kernel shell (PKS) (Loh, 2017). EFB contains relatively high moisture content as high as 60-67% that do not compatible with fuel application and only 62% of PKS is used as a boiler fuel (Hamzah et al., 2019; Lee et al., 2020).

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Several agricultural waste-based fibers have been reported as reinforced fiber, such as wood sawdust and palm kernel shell residues (Atoyebi et al., 2018), coir fiber (Kochova et al., 2020; Stapper et al., 2021), teak wood (Ohijeagbon et al., 2021), balsam tree, and periwinkle shell residue(Odeyemi et al., 2020). Kochova et al. used waste coir fibers as reinforcement in cement-fiber composites (Kochova et al., 2020). The pretreatment affects the fiber surface and hemicellulose content. Thus, the hydration of concrete. Khorami et al. studied the feasibility of the production of fiber cement boards using waste Kraft pulp (Khorami et al., 2016). The waste Kraft pulp shows a low-cost substitute material for cement boards with good mechanical strength. The subtitution of fine agregate to natural fiber decreases the mechanical strength of concrete however still maintaining the high strength and still be clasified as high strength concrete(Matyskova et al., 2024). The additional of abaca fiber from 0-4% produce highest flexural strength at 2% addition (Iqbal et al., 2023).

The natural fiber composite is usually susceptible to high water absorption, fungi, and microbial deterioration. A highly humid and warm environment will increase the deterioration process, thus limiting the application. To overcome this limitation, coating is introduced. The hydrophobic coating was effective in repelling water to maintain the surface of the board dry and clean. The hydrophobic surface mimics lotus or taro leaf (Halim et al., 2022; 2023). Polystyrene from styrofoam waste is one potential polymer to create a hydrophobic surface (Gutierrez-Velasquez et al., 2021; Halim et al., 2023; 2024; Zhao et al., 2017). Here, we explored the empty palm oil fruit bunch and fly ash as a cement board and coated this board with polystyrene waste. The utilization of agricultural waste such as reinforced fiber and polystyrene from styrofoam waste will open the possibility of optimizing the valorization of waste.

MATERIALS AND METHOD

Materials

5 kg of empty palm oil fruit bunch waste was obtained from a local farm. Portland pozzolan cement (PT Semen Indonesia, Indonesia), limestone (local market, Indonesia), fly ash (Paiton power plant waste, Indonesia), toluene technical grade 98% (ROFA Laboratorium Centre), all-purpose cement additive (Damdex, Indonesia), styrofoam waste from domestic waste are used without further purification.

Method

Fresh EFB fiber was shredded to ±10 mm length and then soaked in the hot water for 10 min. Cement: fly ash: limestone: water ratio is 3:0.45:0.45:1 (FA-lime 0.45) and 3:6.6:6.6:5.4 (FA-lime 6.6). EFB was added with the ratio 6%, 8% and 10% of total solid mixture. The superplasticizer is 2% cement weight. All components were mixed using a mixer with 100 rpm (National NV1506, Indonesia) for 5 min. The obtained paste was then cast to acrylic casting for 24 h. The dimensions of casting were 16×4×1 cm and 5×5×5 cm for the flexural strength test and compressive strength test, respectively. The produced boards were then cured for 3, 7, and 28 days. After curing, the boards were then roll coated with 0.5, 0.7, and 1.0% polystyrene solution using toluene as a solvent. The coating was applied 3 times then the sample was air-dried for 24 h.

Characterization

Compressive strength and flexural strength were performed according to the SNI 01-4449-2006 standard (Universal Testing Machine). The density was measured based on Archimedes' law to determine the true volume. A nail resistance test was performed by nailing the samples using a 2 mm diameter of the nail. Then, 1 kg of weight hung on the nail. The hydrophobicity of the cement board surface was characterized by its water contact angle. A sessile drop was captured by a digital camera (Sony DSC-HX350, Indonesia) followed by contact angle measurement using ImageJ software.

RESULTS AND DISCUSSION

The development of fiber-reinforced polymer composites (FRPCs) either from natural or synthetic fiber aims to produce light, corrosion resistance, and fatigue resistance but high strength. Figure 1 shows the density of the cement board for several EFB compositions. The density portrays the tightness, or compactness of the cement board, then affects the physical strength. When EFB content increase, cement board density decreases because the density of EFB (0.14 g/cm^3) is lower of cement (Agustina et al., 2016; Boonyaroj & Saramanus, 2019). The cement board is in a range of 1.6-1.9 g/cm^3 after curing for 28 days. According to SNI

01-4449-2006 (Indonesian National Standard), this board belongs to a high-density cement board (>0.84 g/cm^3). Compare to the local brand of fiber-cement board that require minimum density of ≥1.3 g/cm^3, our board meet the requirement.

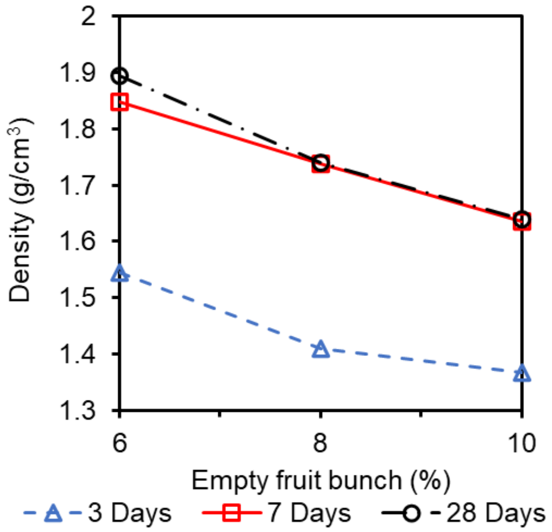

Figure 1. The density of fiber cement board.

Table 1. Classification of high-density cement boards (SNI 01-4449-2006).

Type	Flexural strength (kg/cm^2)
T1 35	≥357
T1 20	≥255
T1 25	≥204

Figure 2 shows the flexural strength of cement board of a) FA-lime 6.6, b) FA-lime 0.45 without superplasticizer and c) FA-lime 0.45 with superplasticizer. Flexural strength is a mechanical strength indicating the tenacity of the board for bending. Flexural strength is important if the board is used as furniture and receives weight. A higher flexural strength means that the board has more resistance to bending while receiving the weight. Higher EFB content increase flexural strength because of high flexibility of cellulose fiber (Halim et al., 2020). Table 1 shows the Indonesian national standard for the fiber cement board (SNI 01-4449-2006) related to flexural strength.

Based on the SNI standard, the board fulfills the minimum criteria of T1 25, T1 20, or T1 35 depending on the variable. For FA-lime 6.6, the flexural strength is lower than the standard for all fiber content, which is 32.3, 48.9, and 70.3 kg/cm^2 for 6, 7, and 8% fiber content, respectively. This variable does not fulfill the minimum criteria. For FA-lime 0.45 without superplasticizer, the flexural strength is 290.8, 345.7, and 362.1 kg/cm^2 for 6, 7, and 8% of fiber content, respectively. The flexural strength of 6% fiber fulfills the requirement of T1 25, 7% fiber fulfills the requirement of T1 20, and 8% fiber fulfills the requirement of T1 35. For FA-lime 0.45 with superplasticizer, flexural strength is 357.3, 372.9, and 380.2 kg/cm^2 for 6, 7, and 8% of fiber content, respectively. Thus, these boards fulfill the requirement of T1 20, T1 25 and T1 35. The low flexural strength of FA-lime 6.6 is caused by high water content. The critical concentration of water should be 0.4; however, in this variable, the water content is as high as 1.8 (Simamora & Harahap, 2015).

Without a superplasticizer, the board fulfills the SNI requirement; however, a superplasticizer will make paste production easier, improve workability, and decrease the board's porosity. The board mass will be more homogeny due to the paste's better flow ability (Utami et al., 2017). The higher content of EFB increases flexural strength because the fiber act as a strengthening and attached place to brittle cement (Jo et al., 2014).

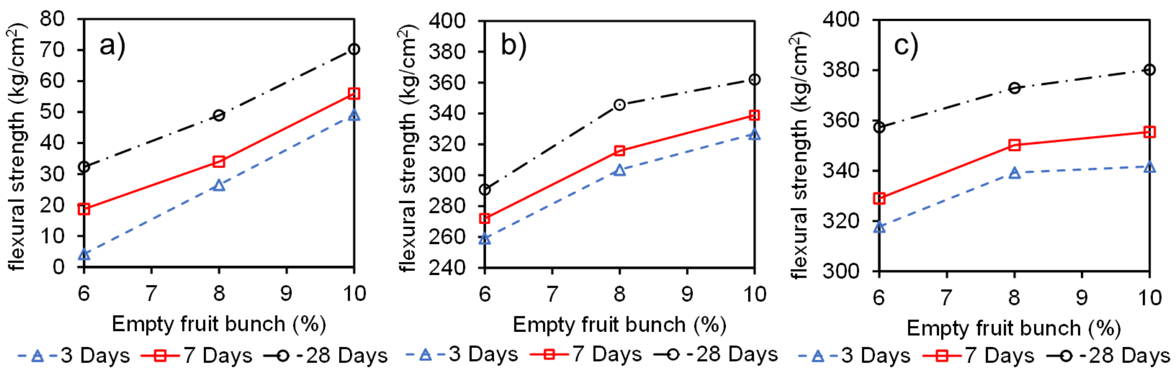

Figure 2. Flexural strength of cement board for a) FA-lime 6.6 b) FA-lime 0.45 without superplasticizer and c) FA-lime 0.45 with superplasticizer.

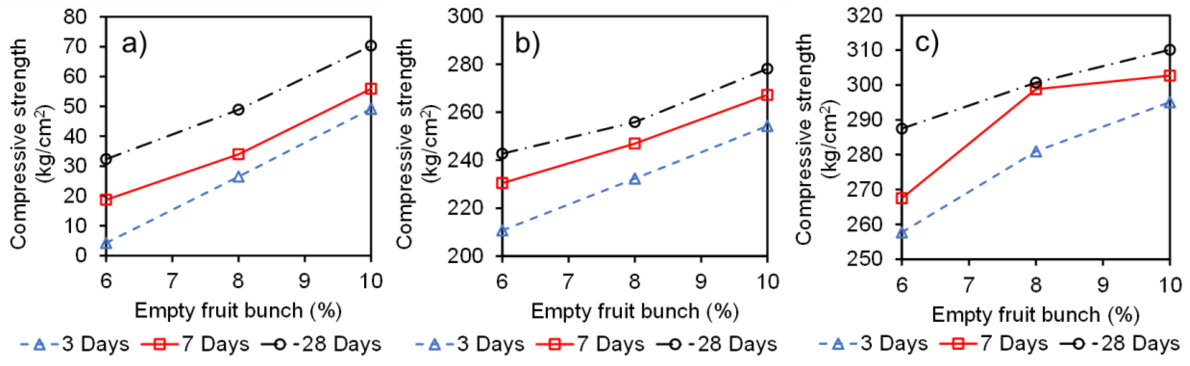

Figure 3. The compressive strength of the cement board for a) cement: fly ash: limestone: water ratio is 3:6.6:6.6:5.4 b) 3:0.45:0.45:1 without superplasticizer and c) 3:0.45:0.45:1 with superplasticizer.

Figure 3 shows the compressive strength of the boards. The compressive strength of FA-lime 6.6 is 43.4, 59.6, and 89.6 kg/cm^2 for 6, 8, and 10% EFB content, respectively. The compressive strength for FA-lime 0.45 without superplasticizer is 290.8, 345.7, and 362.1 kg/cm^2 for 6, 8, and 10% EFB content, respectively. The compressive strength for FA-lime 0.45 with superplasticizer is 357.3, 372.9, and 380.2 kg/cm^2 for the 6, 8, and 10% EFB content, respectively. All results show that with increasing fiber content, compressive strength increases as EFB acts as a filler in cement board (Purwanto, 2016).

FA-lime 6.6 did not meet the minimum requirement of the Indonesian National Standard for cement board (≥82 kg/cm^2). The higher water content will deteriorate the compressive strength of the cement board. The lower water content will increase the compressive strength. However, water content is required to trigger chemical reactions during cement hardening. A high water content could increase flowability but decrease mechanical strength (Simamora & Harahap, 2015). The addition could decrease the need for water.

To extend the application of cement board as furniture, a nail test was conducted. Nail tests indicate whether the board will break during nailing or maintain its shape like a wood board (Figure 4). The board passes the nail test if it maintains the shape without breaking.

As the boards show good mechanical strength, the hydrophobic properties were evaluated. Figure 5 shows the water droplet on the board surface. Even after 4 h, no water droplets permeate the board. Higher polystyrene concentration increases the contact angle. The surface shows hydrophobic properties (θ>90) that are 91.604, 92.075, and 94.055 for 0.5, 0.7, and 1.0% polystyrene, respectively. Contact angle is not as high as previously reported (lower than 150) (Halim et al., 2023) because of the low roughness surface. However, the board has the potential for exterior application.

Figure 4. Nail embedded in the board (10% EFB) without breaking the board for a dimension of 5×5×5 cm (a) and 16×4×1 cm (b). The nail does not detach while weighing 4 kg weight.

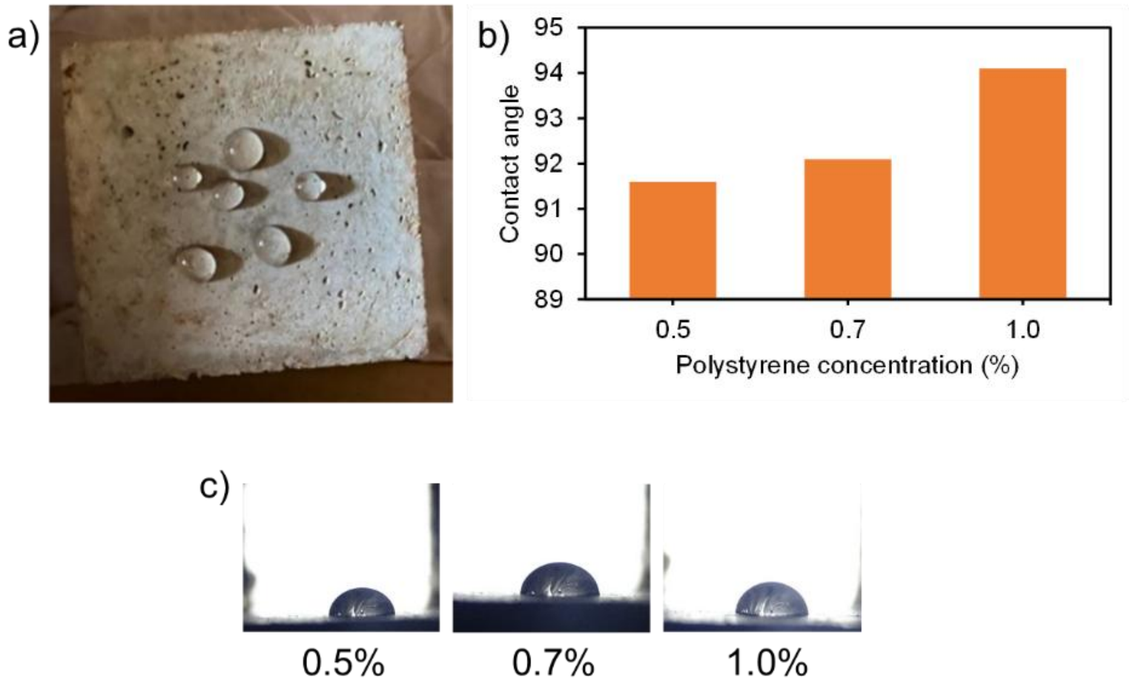

Figure 5. Photograph of water drop on the board surface (a), contact angle of water drop for several polystyrene concentration (b) and photo of contact angle.

CONCLUSION

The empty palm oil fruit bunch as cement board shows high mechanical strength based on its density, flexural strength, and compressive strength. The nail test shows that the board could be nailed without fracturing the structure and maintaining its shape. After coating with polystyrene, the board shows hydrophobic properties, and water droplets permeate the surface even after 4 h. These tests show that the board has a potential application either as interior furniture or as the exterior.

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